【Grant-in-Aid for Scientific Research (S)】

Development of a Super-Pressure Balloon Flying at the World's Highest Altitude

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Purpose and Background of the Research

●Outline of the Research

Scientific balloons enable cost-effective space science experiments but are limited by flight duration. Super-pressure balloons solve this by maintaining a constant volume despite temperature-induced pressure changes, yet current models can only fly at low altitude and require weight reduction. We have developed new technologies to enhance pressure resistance, airtightness, and launch methods, paving the way for lighter super-pressure balloons. Using a high-strength fiber net, a double-layered thin membrane, and a winch-assisted static launch, we improve durability and stability. This study advances these technologies to achieve record-high altitudes, strengthening space transport and enabling rapid scientific experiments.

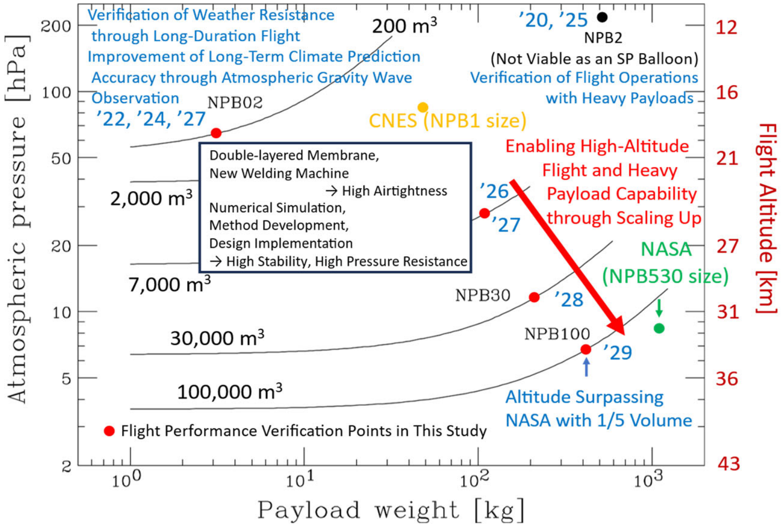

Figure 1. Larger balloons achieve higher altitudes due to the volume-to-surface area relationship. By ensuring airtightness and pressure resistance, we aim to develop a super-pressure balloon capable of reaching the world's highest altitude.

●Research Background

Some studies require placing detectors outside the atmosphere. Initially limited to astronomy and cosmic rays, research now demands larger equipment and spans various fields. However, advancements in space transportation have been gradual, extending experimental cycles and making researcher training more challenging. Balloons have supported space science with low-cost, rapid experiments, but long-duration studies are now essential, surpassing existing balloon capabilities. Small satellites lack the capacity for heavy instruments. Super-pressure balloons, capable of carrying hundreds of kilograms for extended periods at low cost, are in high demand.

●Super-Pressure Balloon with a Net-Covered Membrane

CNES and NASA fly super-pressure balloons at 18 km and 33.5 km, while Japan is still developing this technology. Even NASA's balloons face airtightness challenges and fly lower than conventional ones. In 2010, we identified the potential of lightweight super-pressure balloons by covering the membrane with a net. Starting with proof-of-concept tests, we gradually scaled up while acquiring key technologies. These include developing high-strength net, improving net connections and edge treatment methods, understanding burst pressure determined by deformation (buckling failure), analyzing optimal shapes for stability, and devising launch techniques to prevent impact damage. We are now fully prepared to design, manufacture, and operate large super-pressure balloons.

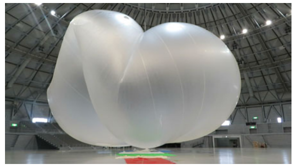

Figure 2. A balloon that fails due to buckling and deformation.

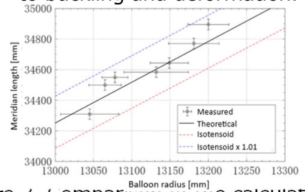

Figure 3. Comparison of the calculated and measured balloon shape.

Expected Research Achievements

●How to Construct a Lightweight Super-Pressure Balloon?

What structure and materials should be used to build a super-pressure balloon capable of reaching the highest altitude with the same weight? Compared to a simple spherical shape, a lobed pumpkin design with meridional ropes and membranes stretched between them (Fig. 4) is superior, as ropes have a higher strength-to-weight ratio than membranes, effectively utilizing their properties. We are further exploring this concept by covering the balloon with a net, creating a diagonally reinforced lobed pumpkin structure (Fig. 5).

Lobed pumpkin balloons can fail due to buckling (Fig. 6), which can be mitigated by increasing the rope angle, though at the cost of added weight. We use numerical simulations to optimize conditions for a lightweight, high-pressure-resistant balloon. A double-layered membrane improves airtightness, and an improved heat-sealing machine prevents gas leaks, ensuring a durable, well-shaped balloon. We aim to reach a higher altitude than NASA's 530,000 m³ balloon with our 100,000 m³ net-covered design. Before full-scale tests, small balloon flights and ground experiments will validate our methods, refining both design and manufacturing. The 200 m³ balloon will help identify potential challenges in long-duration flights and contribute to Antarctic atmospheric gravity wave observations, expanding its scientific potential.

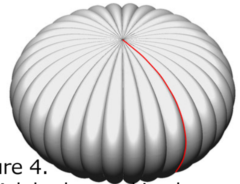

Figure 4. A lobed pumpkin shape.

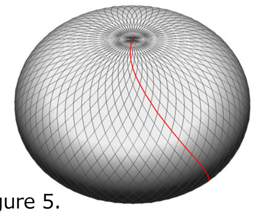

Figure 5. A balloon covered by a net.

Figure 6. A buckling of the lobed pumpkin shaped balloon

●The Future Opened by Lightweight Super-Pressure Balloons

If these balloons prove practical, they will allow low-cost gamma-ray, infrared, and cosmic-ray astronomy, as well as continuous upper-atmosphere and weather monitoring. This could offer an alternative to satellite-based observations. In 2022, and 2024, we conducted Japan's first scientific experiments using super-pressure balloons, leveraging long-duration Antarctic flights to study atmospheric gravity waves - an experiment impossible with satellites. Although this flight used a 200 m³ balloon carrying a 3 kg payload at 18 km, larger balloons will greatly enhance research across scientific fields.

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